

# ADVANCED MACHINING TOWARDS IMPROVED MACHINABILITY OF DIFFICULT-TO-CUT MATERIALS

---

Edited by:

A.K.M. Nurul Amin (Chief Editor)

Dr. Erry Yulian Triblas Adesta

Dr. Mohammad Yeakub Ali



IIUM PRESS

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

**ADVANCED MACHINING**  
**TOWARDS IMPROVED MACHINABILITY OF**  
**DIFFICULT-TO-CUT MATERIALS**

*Edited by:*

*A.K.M. Nurul Amin (Chief Editor)*

*Dr. Erry Yulian Triblas Adesta*

*Dr. Mohammad Yeakub Ali*



**IIUM Press**

Published by:  
IIUM Press  
International Islamic University Malaysia

First Edition, 2011  
©IIUM Press, IIUM

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without any prior written permission of the publisher.

Perpustakaan Negara Malaysia

Cataloguing-in-Publication Data

Advanced Machining Towards Improved Machinability of Difficult-To-Cut Materials: A.K.M.  
Nurul Amin, Erry Yulian Triblas Adesta & Mohammad Yeakub Ali

ISBN: 978-967-418-175-8

Member of Majlis Penerbitan Ilmiah Malaysia – MAPIM  
(Malaysian Scholarly Publishing Council)

Printed by :  
**IIUM PRINTING SDN.BHD.**  
No. 1, Jalan Industri Batu Caves 1/3  
Taman Perindustrian Batu Caves  
Batu Caves Centre Point  
68100 Batu Caves  
Selangor Darul Ehsan  
Tel: +603-6188 1542 / 44 / 45 Fax: +603-6188 1543  
EMAIL: iiumprinting@yahoo.com

<b>SECTION A: HEAT ASSISTED MACHINING</b>	<b>1</b>
1. CHAPTER 1: INFLUENCE OF WORKPIECE PREHEATING ON CHATTER AND MACHINABILITY OF TITANIUM LOY - TI6AL4V	1
2. CHAPTER 2: MACHINABILITY IMPROVEMENT IN END OF MILLING TITANIUM ALLOY TI-6AL-4V THROUGH PREHEATING	9
3. CHAPTER 3: SOME ASPECTS OF IMPROVED MACHINABILITY IN PREHEATED MACHINING OF TITANIUM ALLOY TI-6AL-4V	19
4. CHAPTER 4: MACHINABILITY ASPECTS IN HEAT ASSISTED MACHINING OF HARDENED STEEL AISI H13 USING COATED CARBIDE TOOL	27
5. CHAPTER 5: TOOL WEAR AND SURFACE ROUGHNESS ASPECTS IN HEAT ASSISTED END MILLING OF AISI D2 HARDENED STEEL	35
6. CHAPTER 6: MODELING IN PREHEATED MACHINING OF AISI D2 HARDENED STEEL	43
7. CHAPTER 7: RELATIVE PERFORMANCES OF PREHEATING, CRYOGENIC COOLING AND HYBRID TURNING OF STAINLESS STEEL AISI 304	49
<b>SECTION B: CHATTER AND SELECTED METHODS OF CHATTER SUPPRESSION</b>	<b>57</b>
8. CHAPTER 8: ROLE OF THE FREQUENCY OF SECONDARY SERRATED TEETH IN CHATTER FORMATION DURING TURNING OF CARBON STEEL AISI 1040 AND STAINLESS STEEL	57
9. CHAPTER 9: INFLUENCE OF THE ELASTIC SYSTEM AND CUTTING PARAMETERS ON CHATTER DURING MACHINING OF MILD STEEL	65
10. CHAPTER 10: INFLUENCE OF CHATTER ON TOOL LIFE DURING END MILLING OF ALUMINIUM AND ALUMINIUM ALLOY ON VMC	75

<b>11</b>	<b>CHAPTER 11: A NEW METHOD FOR CHATTER SUPPRESSION AND IMPROVEMENT OF SURFACE ROUGHNESS IN END MILLING OF MILD STEEL</b>	<b>83</b>
<b>12</b>	<b>CHAPTER 12: APPLICATION OF PERMANENT ELECTROMAGNET FOR CHATTER CONTROL IN END MILLING OF MEDIUM CARBON STEEL</b>	<b>91</b>
<b>13</b>	<b>CHAPTER 13: APPLICATION OF PERMANENT ELECTROMAGNET FOR CHATTER CONTROL IN END MILLING OF TITANIUM ALLOY - Ti6Al4V</b>	<b>99</b>
<b>14</b>	<b>CHAPTER 14: CHATTER SUPPRESSION IN END MILLING OF TITANIUM ALLOY Ti6Al4V APPLYING PERMANENT MAGNET CLAMPED ADJACENT TO THE WORKPIECE</b>	<b>107</b>
	<b>SECTION C: MODELING AND OPTIMIZATION IN MACHINING</b>	<b>117</b>
<b>15</b>	<b>CHAPTER 15: A COUPLED ARTIFICIAL NEURAL NETWORK AND RSM MODEL FOR THE PREDICTION OF CHIP SERRATION FREQUENCY IN END MILLING OF INCONEL 718</b>	<b>117</b>
<b>16</b>	<b>CHAPTER 16: APPLICATION OF RESPONSE SURFACE METHODOLOGY COUPLED WITH GENETIC ALGORITHM FOR SURFACE ROUGHNESS OF INCONEL 718</b>	<b>123</b>
<b>17</b>	<b>CHAPTER 17: DEVELOPMENT OF A MATHEMATICAL MODEL FOR THE PREDICTION OF SURFACE ROUGHNESS IN END MILLING OF STAINLESS STEEL SS 304</b>	<b>133</b>
<b>18</b>	<b>CHAPTER 18: DEVELOPMENT OF AN ARTIFICIAL NEURAL NETWORK ALGORITHM FOR PREDICTING THE CUTTING FORCE IN END MILLING OF INCONEL 718 ALLOY</b>	<b>143</b>
<b>19</b>	<b>CHAPTER 19: DEVELOPMENT OF AN ARTIFICIAL NEURAL NETWORK ALGORITHM FOR PREDICTING THE SURFACE</b>	<b>149</b>
<b>20</b>	<b>CHAPTER 20: DEVELOPMENT OF TOOL LIFE PREDICTION MODEL OF TiAlN COATED TOOLS DURING PART C: HIGH SPEED HARD MILLING OF AISI H13 STEEL</b>	<b>155</b>
<b>21</b>	<b>CHAPTER 21: MODELING FOR SURFACE ROUGHNESS IN END-MILLING OF TITANIUM ALLOY Ti-6Al-4V USING UNCOATED WC INSERTS</b>	<b>161</b>

22	CHAPTER 22: MODELING OF SURFACE ROUGHNESS DURING END MILLING OF AISI H13 HARDENED TOOL STEEL	167
23	CHAPTER 23: MODELING OF TOOL LIFE USING RESPONSE SURFACE METHODOLOGY IN HARD MILLING OF AISI D2 TOOL STEEL	175
24	CHAPTER 24: OPTIMIZATION OF SURFACE ROUGHNESS IN HIGH SPEED END MILLING OF TITANIUM ALLOY Ti-6Al-4V UNDER DRY CONDITION	181
25	CHAPTER 25: COMPARISON OF SURFACE ROUGHNESS IN END-MILLING OF TITANIUM ALLOY Ti-6Al-4V USING UNCOATED WC-CO AND PCD INSERTS THROUGH GENERATION OF MODELS	189
26	CHAPTER 26: ASSESSMENT OF PERFORMANCE OF UNCOATED AND COATED CARBIDE INSERTS IN END MILLING OF Ti-6Al-4V THROUGH MODELLING	195
	SECTION D: CRYOGENIC AND HIGH SPEED MACHINING OF METALS AND NON METALS	203
27	CHAPTER 27: THE EFFECT OF CRYOGENIC COOLING ON MACHINABILITY OF STAINLESS STEEL DURING TURNING	203
28	CHAPTER 28: COMPARISON OF MACHINABILITY OF CERAMIC INSERT IN ROOM TEMPERATURE AND CRYOGENIC COOLING CONDITIONS DURING END MILLING INCONEL 718	209
29	CHAPTER 29: HIGH SPEED END MILLING OF SINGLE CRYSTAL SILICON SING DIAMOND COATED TOOL	217
30	CHAPTER 30: IMPLEMENTATION OF HIGH SPEED OF SILICON USING DIAMOND COATED TOOLS WITH AIR BLOWING	225
31	CHAPTER 31: ELIMINATION OF BURR FORMATION DURING END MILLING OF POLYMETHYL METHACRYLATE (PMMA) THROUGH HIGH SPEED MACHINING	233
32	CHAPTER 32: WEAR MECHANISMS IN END MILLING OF INCONEL 718	239

33	CHAPTER 33: PERFORMANCE OF UNCOATED WC-CO INSERTS IN END MILLING OF ALUMINUM SILICON CARBIDE (ALSiC)	247
34	CHAPTER 34: APPLICATION OF PCD INSERTS IN END MILLING OF ALUMINUM SILICON CARBIDE (ALSIC)	253
35	CHAPTER 35: EFFECTS OF SCRIBING WHEEL DIMENSIONS ON LCD GLASS CUTTING	259

**Chapter 5****Tool Wear and Surface Roughness Aspects in Heat Assisted End Milling of AISI D2 Hardened Steel**

A.K.M. Nurul Amin<sup>1\*</sup>, M.A. Lajis<sup>2</sup>, A.N. Mustafizul Karim<sup>3</sup>

<sup>1,3</sup>Faculty of Engineering- International Islamic University Malaysia

<sup>2</sup>Faculty of Mechanical and Manufacturing Engineering – UTHM, Malaysia

e-mail address of corresponding author: [akamin@iium.edu.my](mailto:akamin@iium.edu.my)

---

**1.0 INTRODUCTION**

With the advent of several advanced difficult-to-cut materials, and with the availability of heat resistant tool materials has posed a great challenge in industries. Hardened steel is one of these difficult-to-cut materials. During the last few decades numerous studies have been conducted to improve the machinability of these materials and many large organizations have invested considerably in exploring and developing new techniques to minimize machining costs of these materials while maintaining their quality requirements. The benefits for the manufacture of components from hardened steel are substantial in terms of reduced machining costs and lead times, in comparison to the more traditional route which involves machining in the annealed state, heat treatment, grinding or electrical discharge machining (EDM), and manual finishing [1]. Recent advances in cutting tool and machine tool technologies have opened up new opportunities for investigation in machining hard materials and especially for bulk removal of material. For these reasons the growing interest for hot machining process is being developed in industry. In this method work-piece is softened by heating and thereby shear strength is reduced [2]. The technology of hot machining is not new. Previous generations of this technology employed low-grade heat sources such as flame, electrical resistance, induction and plasma arcs [3]. Ozler et al. [4] integrated plasma gas heating in turning of austenitic manganese steel and he noticed that tool life increases when heating temperatures increased.

Preheating of workpiece by induction heating has been recently reported to enhance the machinability of materials. The latest current work done by Amin et al [5] when he carried out preheated induction heating in end milling of AISI D2 hardened steel using Poly Crystalline Cubic Boron Nitride (PCBN) inserts. He observed that preheated machining of the material leads to surface roughness values well below 0.4  $\mu\text{m}$ , such that the operations of grinding as well as polishing can be avoided at the higher cutting speeds. He added that preheated machining has been able to reduce the amplitude of the lower frequency mode of chatter by almost 4.5 times at the cutting speed of 50 m/min. The primary causes of this stable cutting need to be studied in the perspective of material properties and damping capability of the material in the preheated condition. The primary objective of preheating is to enhance the ductility of the material for easier chip formation and better chip flow over the rake surface of the tool. In addition preheating is expected to improve the tool life and improve surface finish of the machined